Turbocompressor thrust predictive maintenance

Which way is it going?

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A great deal of time is spent trouble-shooting the causes of thrust changes. Considering the potential for a long-term machinery outage in the event of a thrust failure, this article will cover the important aspects of thrust condition monitoring and predictive maintenance.

Today, most modern turbocompressors installed for critical service (unspared duty) are equipped with condition monitoring that helps the end-user determine the mechanical condition of the equipment. Typical thrust bearing condition monitoring devices include:

- Thrust displacement monitors (usually dual voting)
- Thrust bearing pad temperature devices
- Balance line flow indicators (differential pressure indicators)

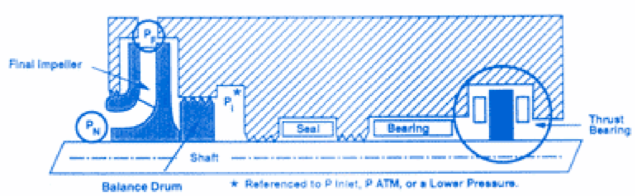
Often, thrust direction and change causes confusion. Many hours have been spent trying to determine the actual active thrust direction. In many instances, the active thrust direction was assumed to be towards the suction if the direction was not specifically stated in the vendor's instruction book. This article presents some practical ways to define thrust direction that can serve as an aid in thrust bearing predictive maintenance. Remember that the majority of machines installed in the field have a balance drum to reduce natural thrust (Figure 1). The absence of a drum can, in many cases, cause thrust bearing failure. Many events, such as surge, liquid ingestion, rotor imbalance, gas composition and inlet temperature changes, can occur within the turbocompressor that will result in thrust bearing failure.

Causes of thrust

Figure 2 shows a typical compressor impeller and the direction of leakage from the discharge of the impeller to the labyrinths. As a result of the pressure ratio created by the impeller, a thrust force is generated which acts from the hub side (backside) of the impeller towards the suction side. In addition, changes in gas composition, inlet temperature, speed and adjustable guide van angle will cause compressor ratio variations and result in thrust changes.

Figure 2 shows the basis for thrust calculations. The average thrust of each impeller is calculated and summed to determine the net thrust of the rotor. If this thrust exceeds the capability of the thrust bearing, a balance drum or opposed configuration to reduce the rotor thrust is required. Most industry specifications today require a safety factor of approximately 2 to 1 between the thrust bearing design capability and the rotor thrust. As a result, a balance drum or a balanced opposed rotor configuration is usually required to allow a reasonable safety margin between the rotor thrust and thrust bearing rating.

It is possible that balance drum seal deterioration will result in significantly ►



Total Impeller Thrust (LB) = Σ Individual Impeller Thrust
Balance Drum Thrust (LB) = (P_F - P_I) x (Balance Drum Area)
Thrust Bearing Load (LB) = Total Impeller Thrust – Balance Drum Thrust

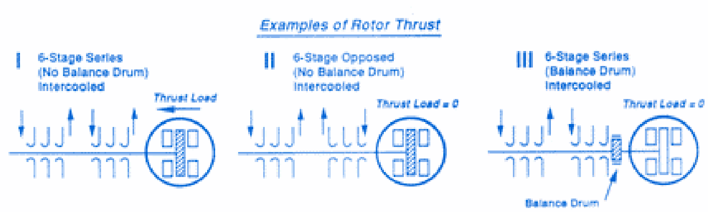


Figure 1
Rotor thrust force

increased rotor thrust and possible thrust bearing failure. Thrust bearing failure during operation can result in significant rotor and compressor internal damage. Considering that many end-users do not stock spare internal compressor parts, a significant thrust bearing failure can render a machine inoperable for weeks or even months. Therefore, there is great need for effective thrust condition monitoring.

Thrust condition monitoring

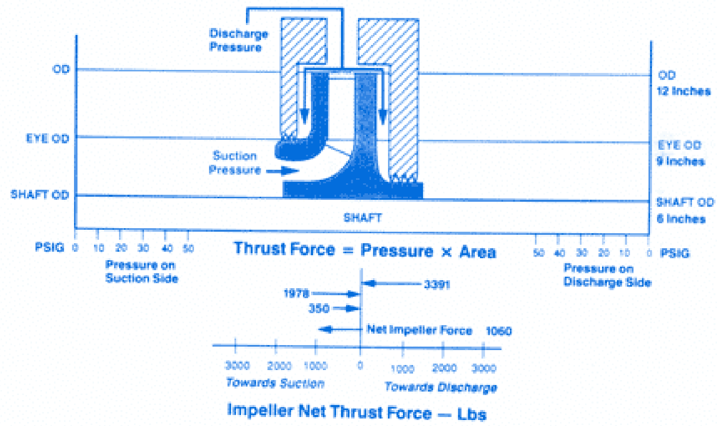
Refer to Figure 3 and observe the various configurations of rotor thrust. Configuration 1 shows a six stage rotor without a balance drum. It is interesting to observe the shape of the curve; it looks exactly like a performance curve. It should, since the cause of rotor thrust is the performance characteristic of the turbocompressor. When we consider that the performance of any turbocompressor changes as a function of flow, speed, guide vane angle, gas composition and inlet temperature, it can be seen that the thrust can, and will, change during normal operation. Therefore, it is important to accurately monitor thrust. Figure 3 also shows that the direction of thrust can vary depending upon the rotor configuration, the sizing of the balance drum and the operating flow rate of the unit. Many vendors size the balance drum so the direction of thrust will not change during operation. However, many existing machines in the field exhibit the characteristic of thrust change as a function of flow. Unless this is understood, rapid changes in thrust direction can cause significant concern.

Many people do not know the active thrust direction for their machine, nor do they realize that the direction can change as a result of machine condition. It is beneficial to label the thrust direction as a function of the specific machine. That is, during the shutdown of the machine, push the rotor and observe the direction of the thrust displacement monitor, and label the monitor accordingly. For example, if a rotor pushed towards the suction causes the thrust displacement pointer to rise, label the meter "towards suction end." This action will enable the reliability personnel and operators who are onsite to determine the direction in which thrust is acting and can greatly aid in predictive maintenance practices.

If the thrust (axial displacement) sensors are set up correctly, according to plant convention regarding polarity and value, during the compressor assembly float check, it should be obvious which direction is "normal" thrust. Furthermore, any later change will be clearly understood.

Compressor vendors can supply, for a minimum engineering fee, a curve similar to Figure 3 that will approximate the direction of thrust change as a function of flow. This information can greatly help determine the internal condition of the machine. If there is a significant amount of thrust displacement direction change, other parameters can be used to determine possible root causes.

Calculation of turbocompressor performance change, measurement of balance line flow (or differential pressure)



Example:

For an impeller with:

OD = 12 inches

EYE OD = 9 inches

Shaft OD = 6 inches

Pressure on suction side = 10 lbs

Pressure on discharge side = 40 lbs

Using the following formulas, you can calculate the force on the discharge side of the impeller, the discharge pressure on the suction side of the impeller and the force on the suction side of the impeller. This calulation assumes no pressure gradient on the suction side of the impeller. In actual operation, the average pressure on the suction side of the compressor would be less than 40 psig, resulting in a greater value of impeller thrust.

$A = \pi r^2$

Force = Pressure x Area

Example:

Force on discharge side of the impeller

= (Pressure on discharge side) (Area)

= (40 psig) π (6^2 - 3^2)

= 3391 lbs

Discharge pressure on suction side of impeller

= (Pressure on hub) (Area)

= (40 psig) π (6^2 - 4.5^2)

= 1978 lbs

Force on suction side

= (Pressure on the side plate) (Area)

= (10 psig) π (4.5^2 - 3^2)

= 353 lbs

Impeller Thrust

= Discharge force on the discharge side - Total of the discharge force on suction side of impeller plus the suction force.

= 3391 - (1978 + 353)

= 1060 lbs

Therefore, the net impeller thrust force is towards the suction.

Figure 2
Impeller thrust force

and measurement of thrust pad temperature rise can all be useful to determine the reason for thrust bearing position change. Often the change is merely the result of a shift in the direction of thrust, and, depending on the balance drum design and machine configuration, this action can be perfectly normal. In this case, monitoring of the thrust pad bearing temperatures is extremely helpful to determine if, in fact, the change is the result of a significant increased thrust load.

If the bearing pad temperatures are low (approximately 150 to 175°F (66 to 79°C)), this action is merely a result of a change of thrust direction. A significant change in thrust displacement with an accompanying temperature increase in the pads is worth noting. The possible cause can be investigated by observing the performance data and calculating performance and balance drum flow.

Another point that is frequently overlooked is the fact that there is a significant change between the thrust bearing clearance when the machine is not running and the thrust bearing clearance during operation. The force on the active operating thrust bearing face is well in excess of the maximum force that can be produced during shutdown by moving the rotor to check the thrust. Thus, during operation, this high force will compress the components of the thrust bearing pads, leveling plates, backing plates and thrust shims. It is not uncommon to experience a change of thrust clearance between shutdown and operation in excess of twice the shutdown clearance. Therefore, alarms and trip settings must be carefully made. Remember that thrust bearing position monitoring is usually the only trip associated with the thrust bearing system. Therefore, care must be taken so unnecessary trips do not occur because the actual thrust clearances during operation are misunderstood.

The final item which affects thrust condition monitoring is balance line flow indication. Installation of a pressure tap at the exit of the balance line from the discharge end of the machine and the entrance to the suction end of the machine (or an intermediate pressure point) will enable a differential water pressure gauge to be installed that will monitor changes in balance line flow. Remember that the generation of rotor thrust is also a function of the balance drum's leakage flow. Since the balance drum is internal to the machine and represents significant disassembly time during turnaround, it is of utmost importance to know its condition.

Conclusion

Effective thrust monitoring, with comparison of baselines after turnaround to changes prior to the next scheduled plant turnaround, can truly make a predictive maintenance program more effective. The result is a turbocompressor that can operate with optimum levels of safety and reliability. ■

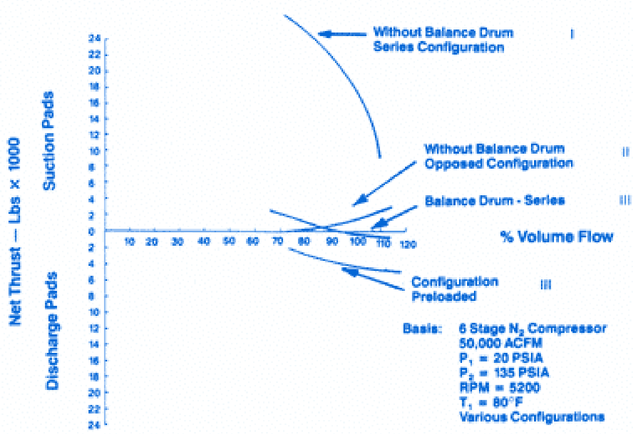


Figure 3
Net thrust load versus percent flow